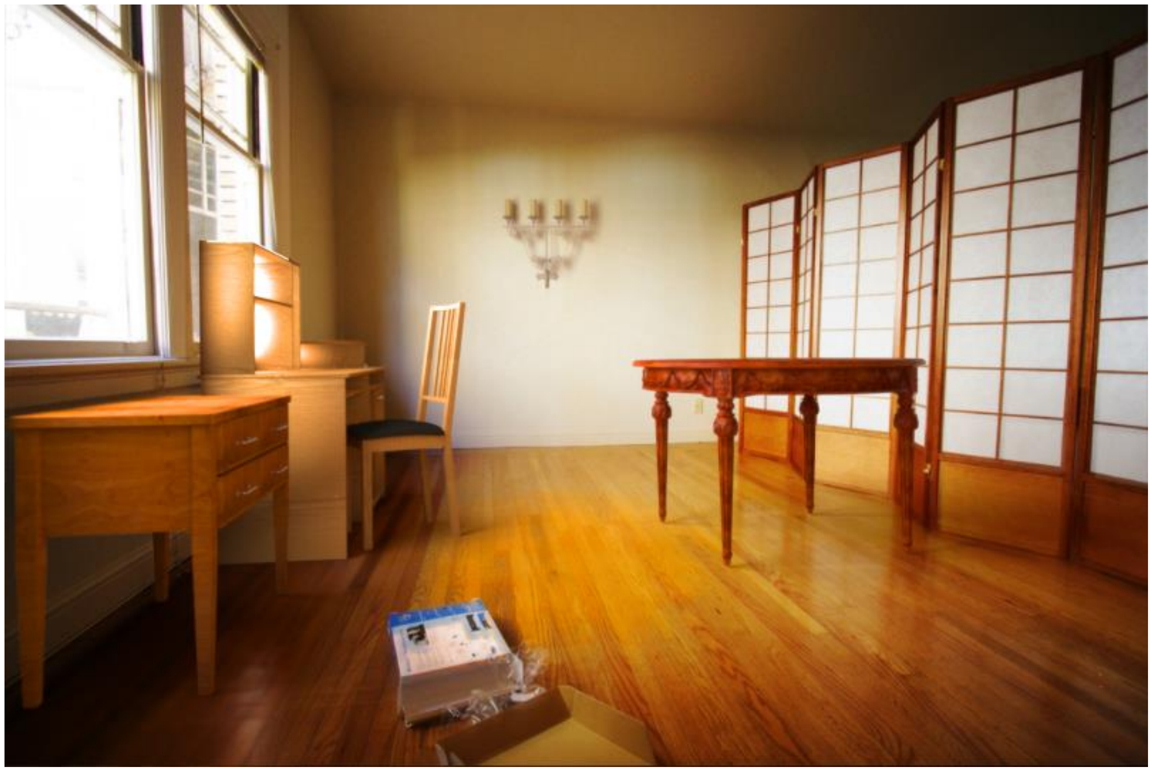
10/21/14

The image as a virtual stage



Computational Photography

Derek Hoiem

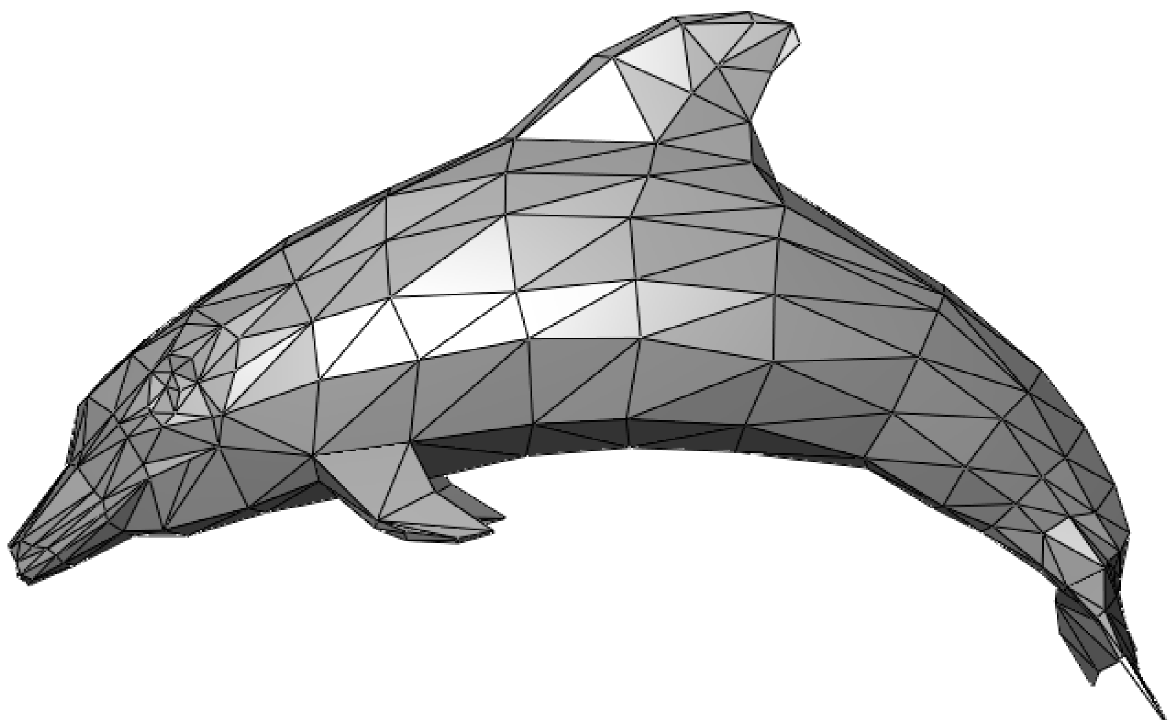
Adapted from slides by Kevin Karsch

Today

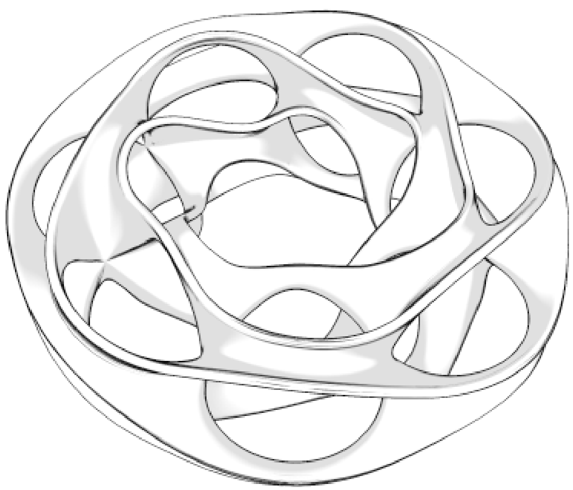
- Inserting objects into *legacy* photos
  - Uses single-view geometry and image-based lighting concepts
- Using Blender

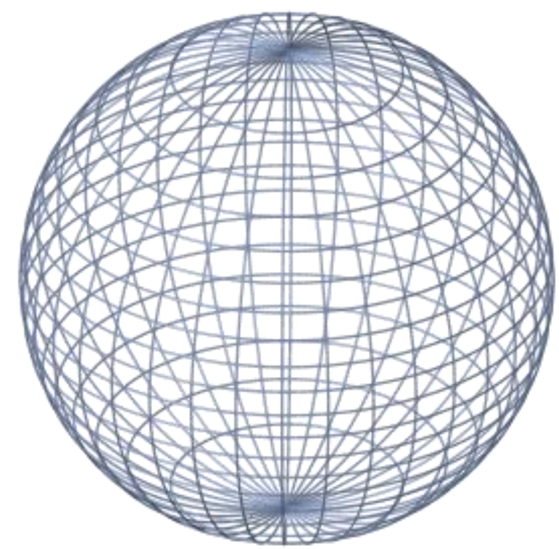
The polygonal mesh

- Discrete representation of a surface
  - Represented by vertices -> edges -> polygons (faces)



Insert these…



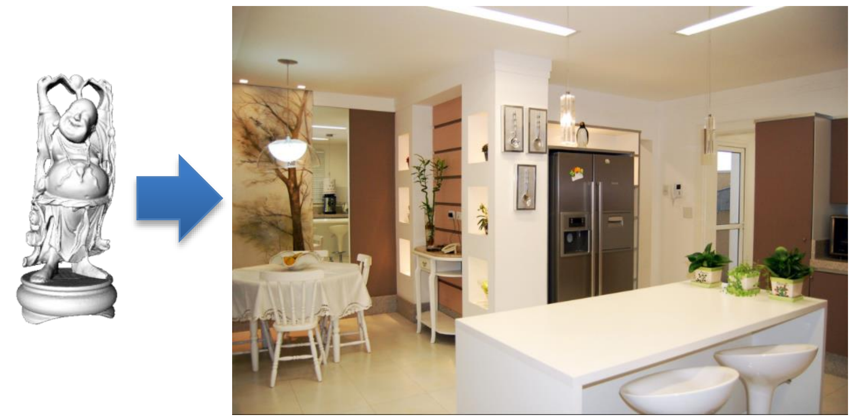


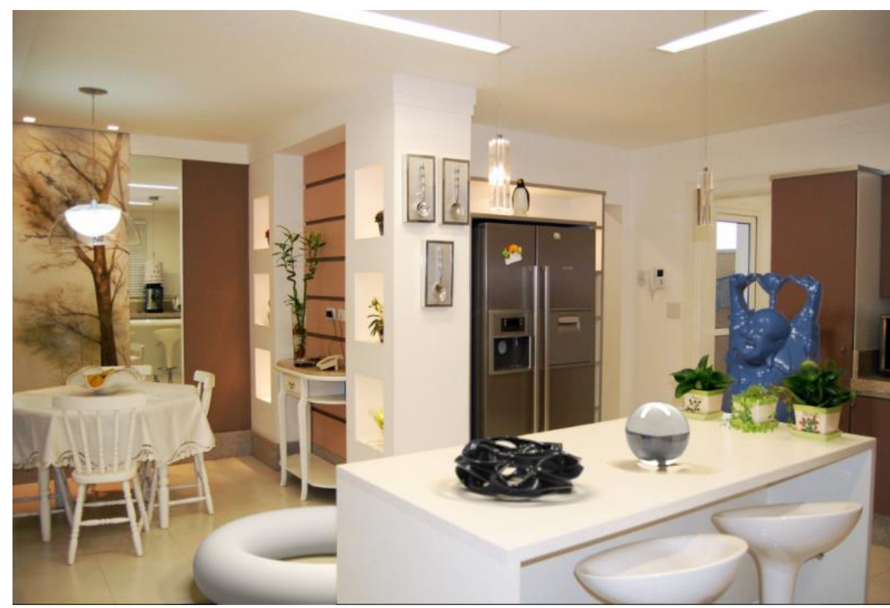
…into this

…into this

Inserting 3D objects into photographs

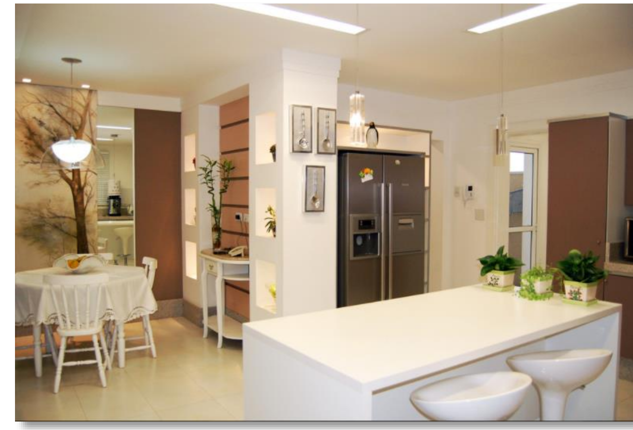
- Goal: Realistic insertion using a single LDR photo
- Arbitrary lighting environments
- Intuitive, quick and easy to create content
  - Home planning/redecoration
  - Movies (visual effects)
  - Video games

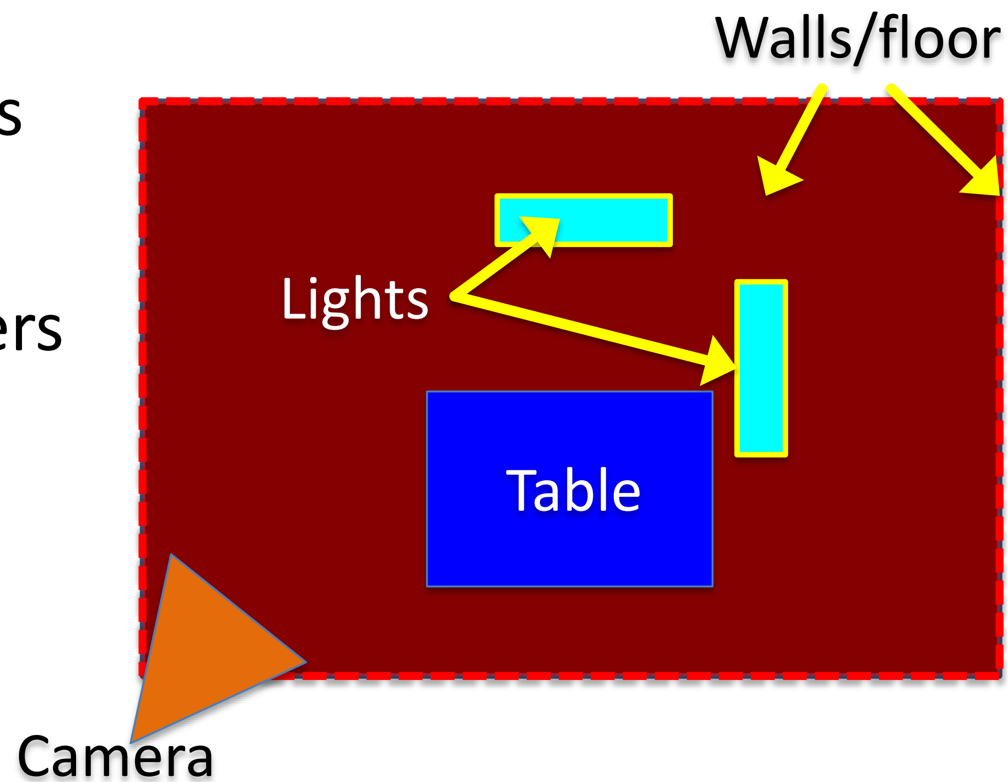




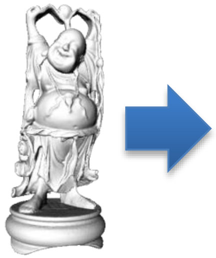
Challenges

- Estimate a physical scene model including:
  - Geometry
  - Surface properties
  - Lighting info
  - Camera parameters





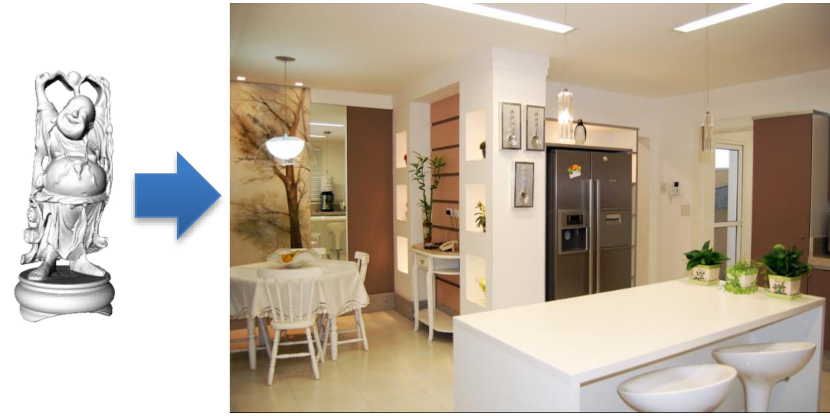
Earlier approaches with scene access



Manual authoring

[Fournier et al. ’93]

Earlier approaches with scene access



Manual authoring

[Fournier et al. ’93]

Light probe, Inverse GI

[Debevec ’98, Yu et al. ‘99]

Earlier approaches <u>without</u> scene access

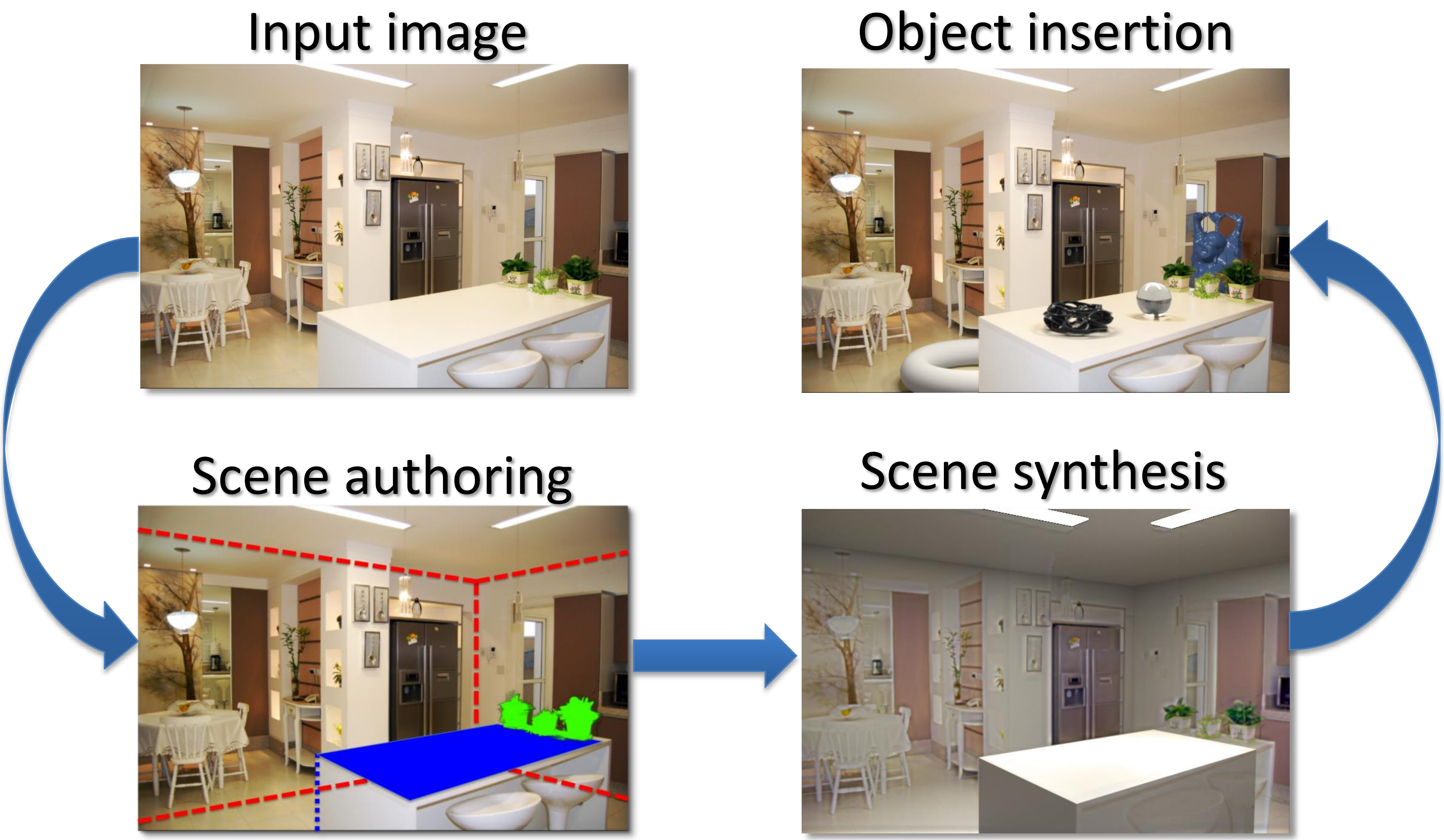
Outdoor illumination

[Lalonde et al. ‘09]

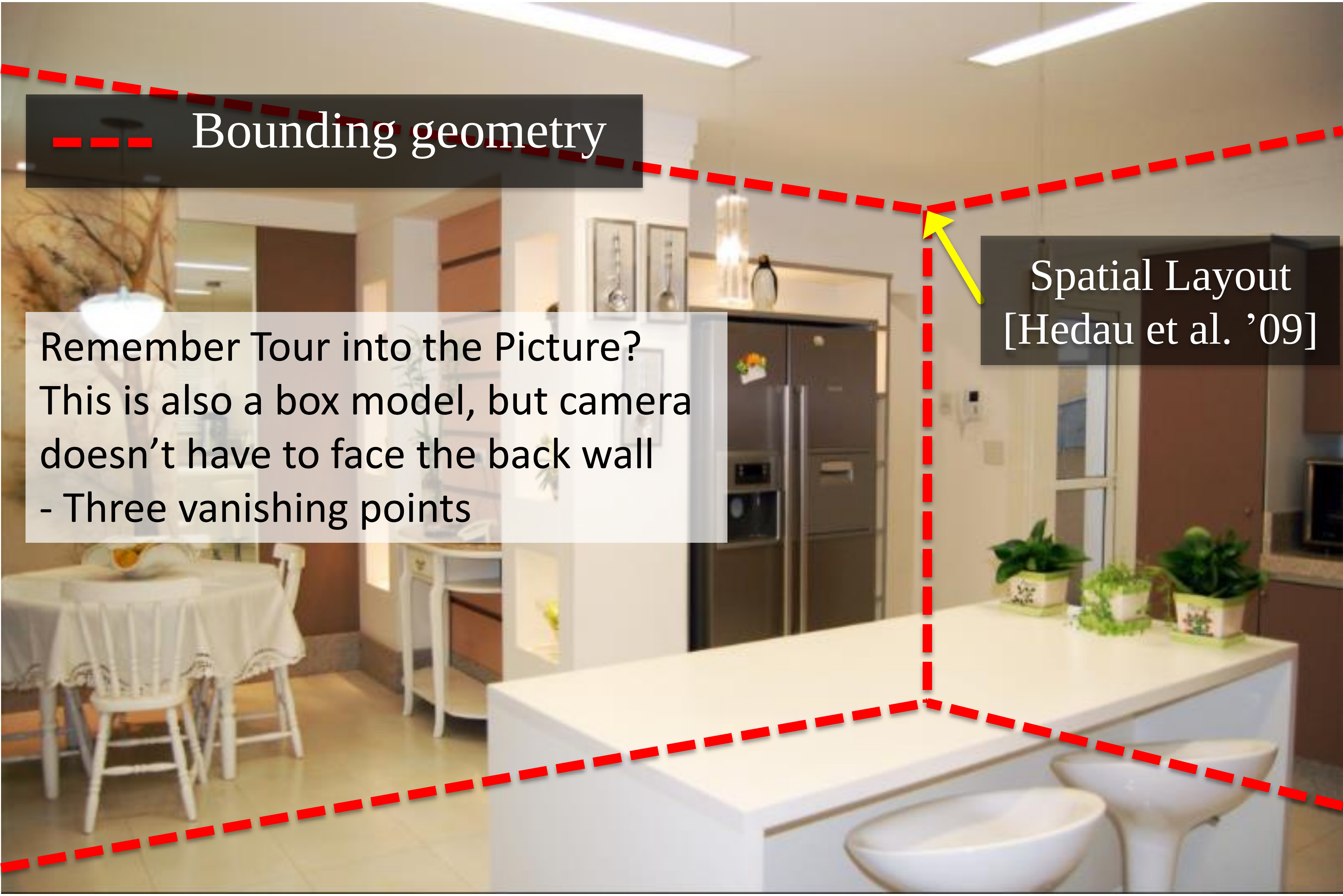
Point source detection

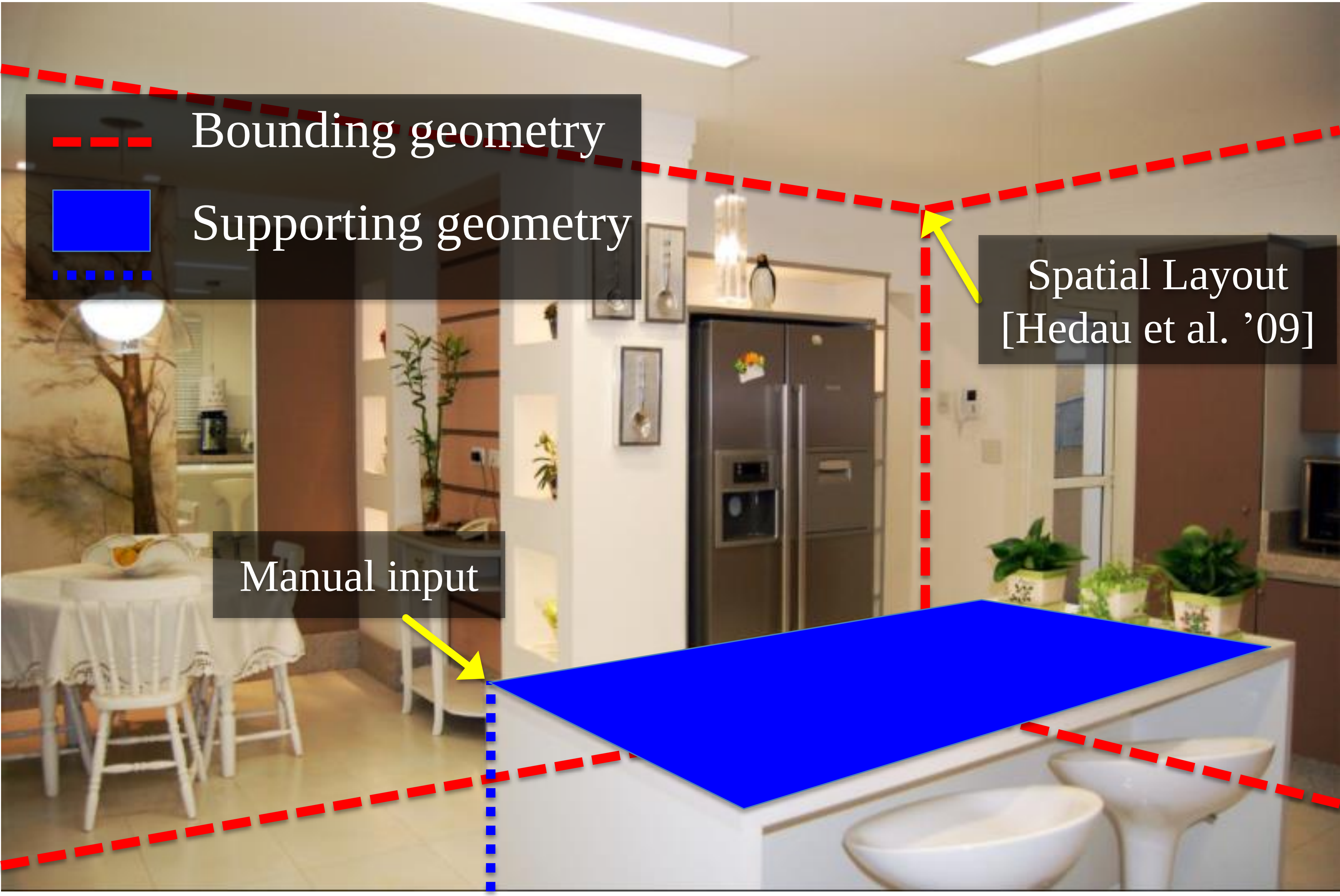
[Wang and Samaras ’03, Lopez-Moreno et al. ‘10]

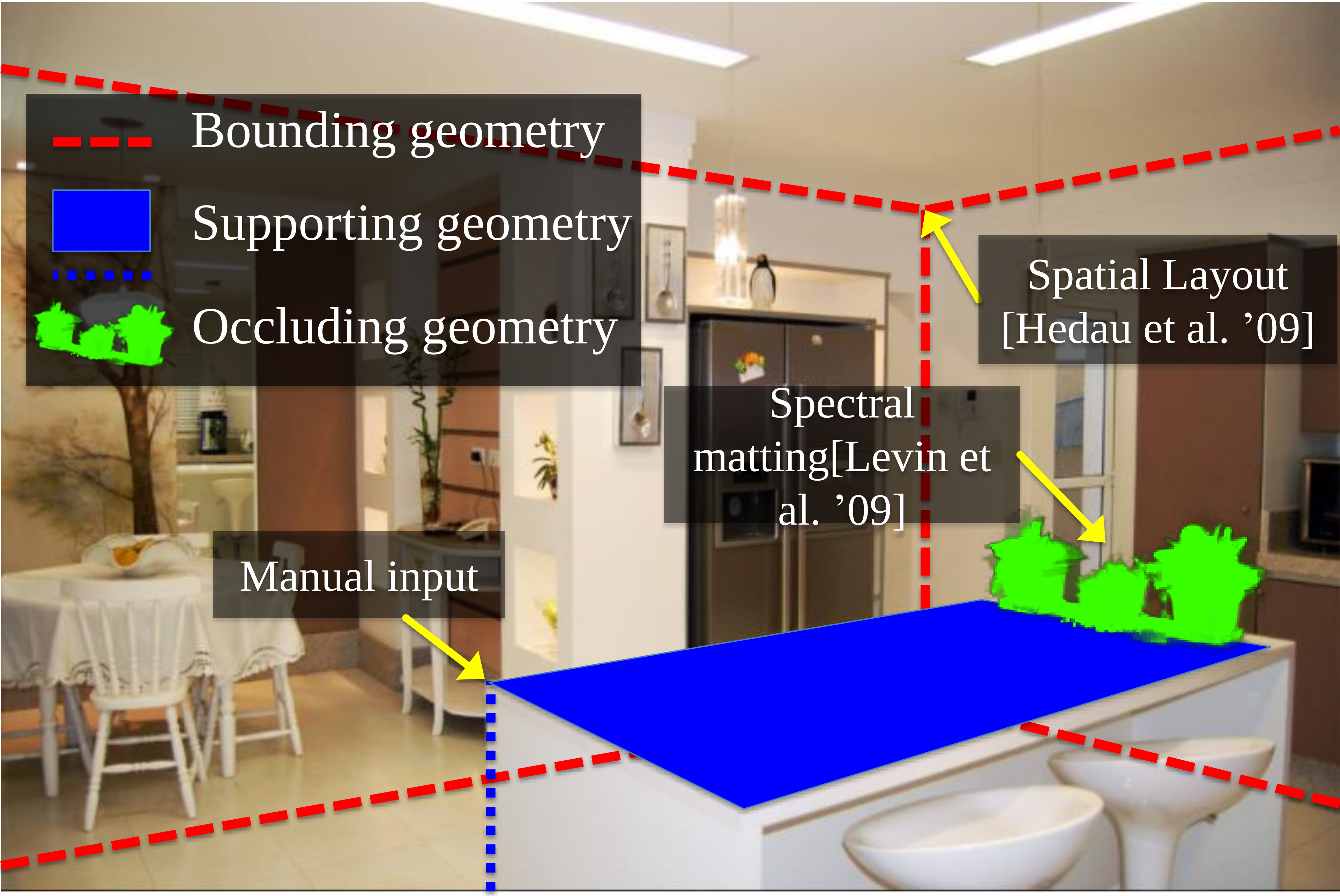
System overview



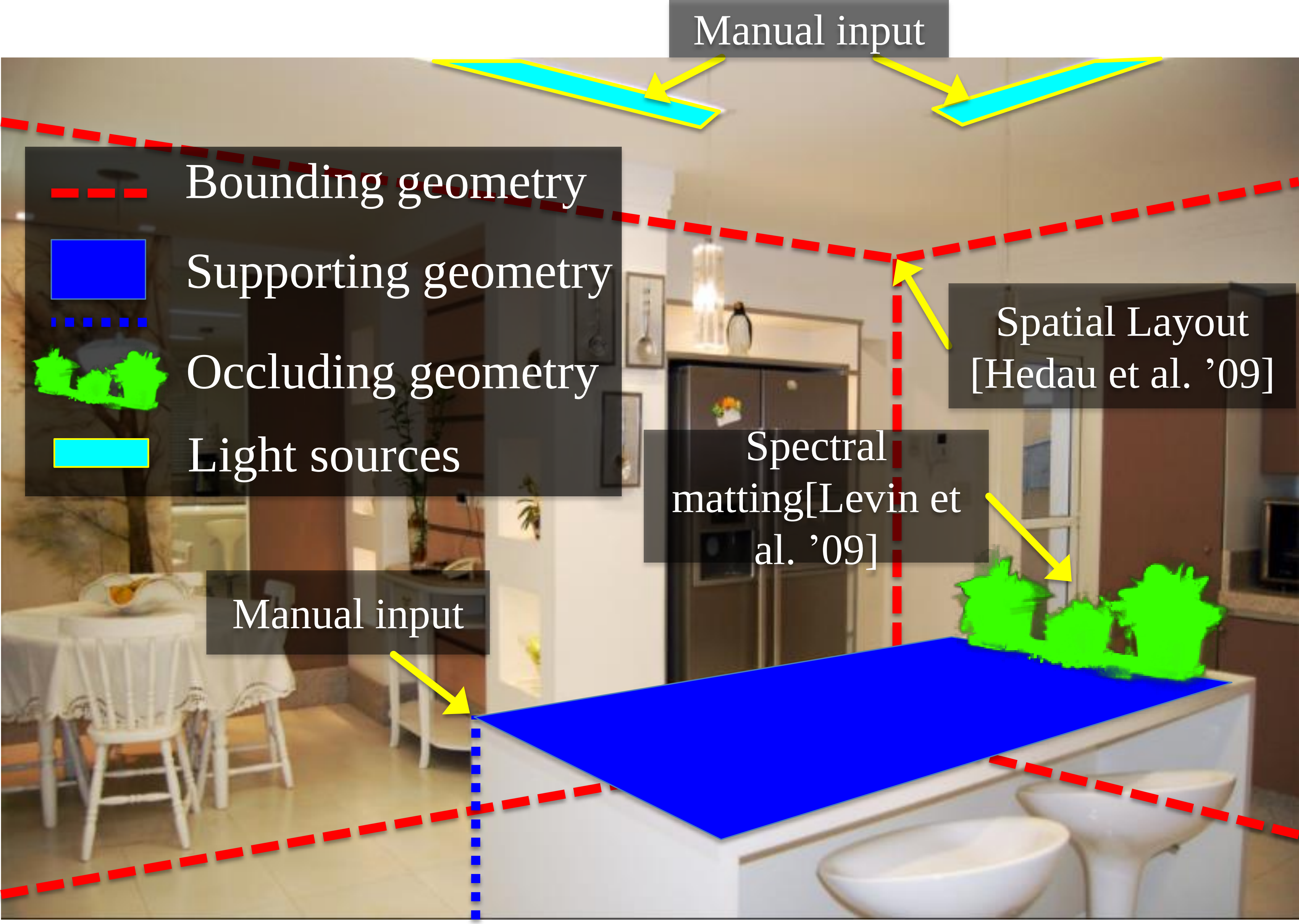
Overview of getting geometry and lighting


Bounding geometry
Spatial Layout
[Hedau et al. '09]
Remember Tour into the Picture?
This is also a box model, but camera
doesn't have to face the back wall
- Three vanishing points

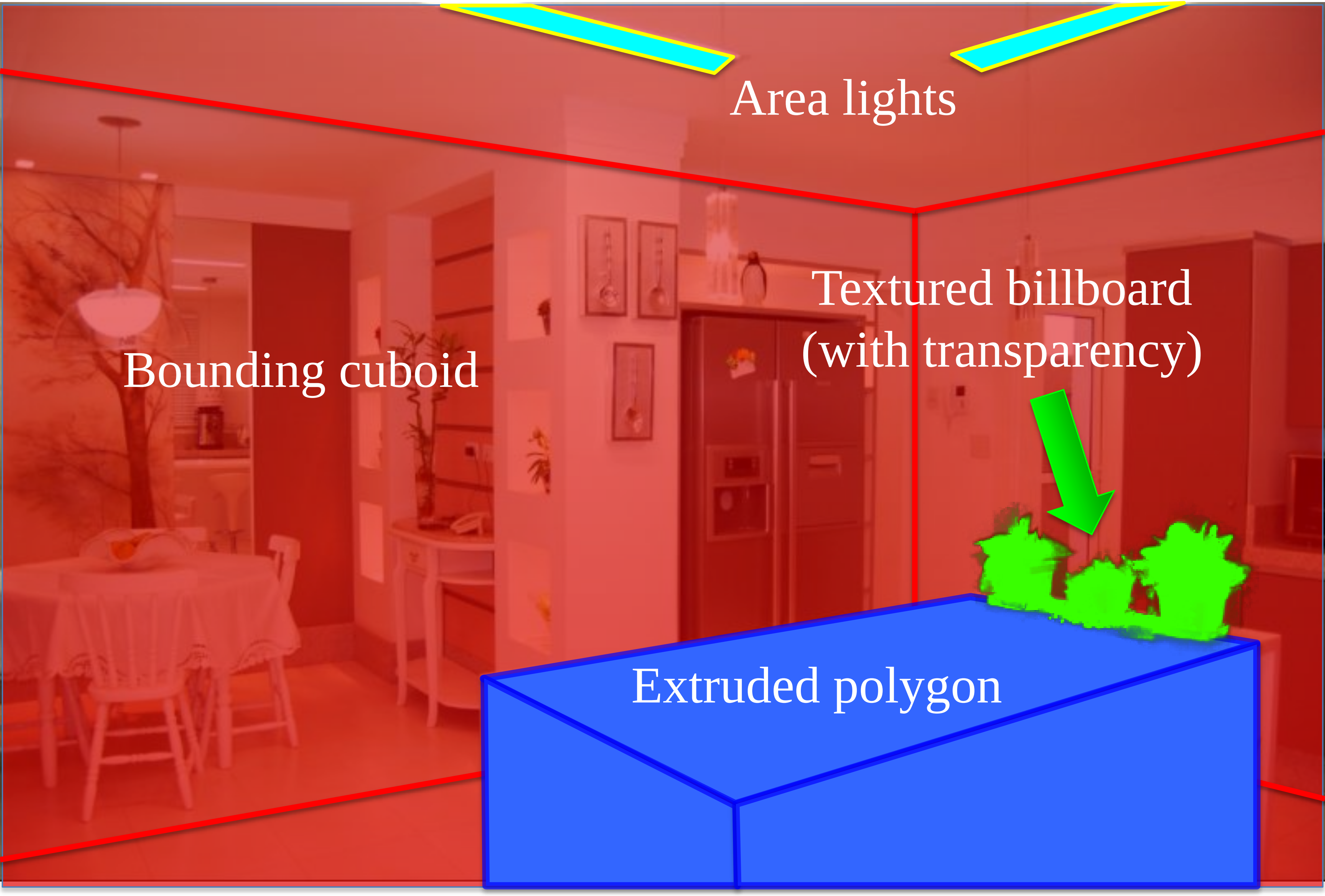

Bounding geometry
Supporting geometry
Spatial Layout
[Hedau et al. '09]
Manual input



Bounding geometry
Supporting geometry
Occluding geometry
Spatial Layout [Hedau et al. ’09]
Spectral matting[Levin et al. ’09]
Manual input



Manual input
Bounding geometry
Supporting geometry
Occluding geometry
Light sources
Spatial Layout
[Hedau et al. ’09]
Spectral
matting[Levin et
al. ’09]
Manual input


Area lights
Textured billboard
(with transparency)
Bounding cuboid
Extruded polygon

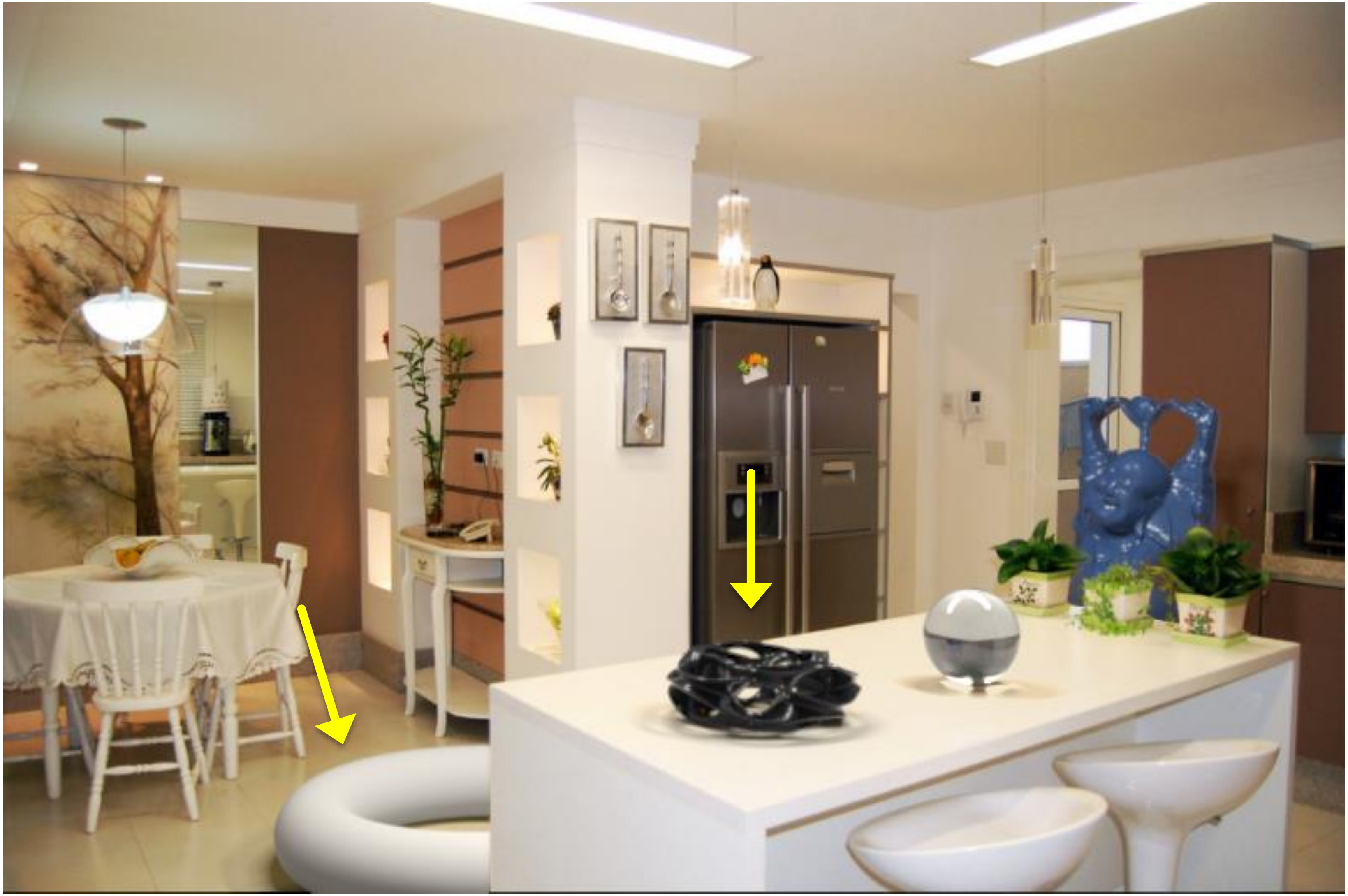
What the spatial layout provides

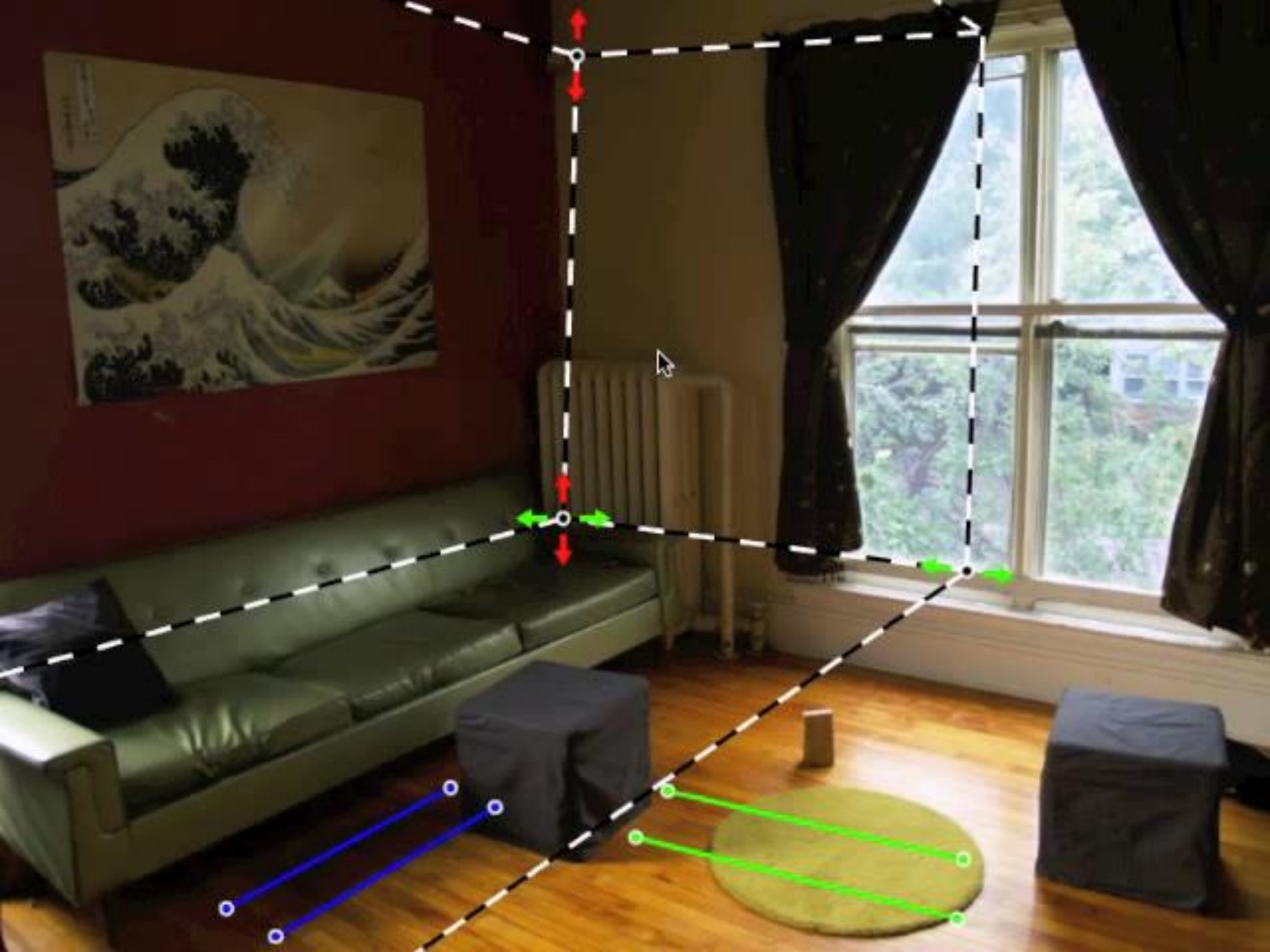
Extruded geometry, billboards enable *occlusion*

Box, supporting surfaces enable *object placement*

Box, extruded geometry, lighting enables *shadows, inter-reflections, caustics*

Camera geometry ensures correct *perspective*





Solving for camera viewpoint

Given 3 orthogonal VPs (at least two finite), can compute projection operator

2D point in homogeneous coordinates

3D point in Cartesian coordinates

$$\lambda p_2 = KRP_3$$

Intrinsic camera matrix

Rotation matrix

Solving for camera viewpoint

Given 3 orthogonal VPs (at least two finite), can compute projection operator: intrinsic matrix

$$K = \begin{bmatrix} f & 0 & u_0 \\ 0 & f & v_0 \\ 0 & 0 & 1 \end{bmatrix} K^{-1} = \begin{bmatrix} 1/f & 0 & -u_0/f \\ 0 & 1/f & -v_0/f \\ 0 & 0 & 1 \end{bmatrix}$$

$$e_i = (1,0,0)^T, e_j = (0,1,0)^T, e_k = (0,0,1)^T$$

$$v_i = KRe_i, v_j = KRe_j, v_k = KRe_k$$

$$(KR)^{-1}v_i = e^i, (KR)^{-1}v_j = e^j, (KR)^{-1}v_k = e^k$$

$$e_i^T e_j = e_j^T e_k = e_i^T e_k = 0$$

$$v_i^T K^{-T} R R^{-1} K^{-1} v_j = v_j^T K^{-T} R R^{-1} K^{-1} v_k = v_i^T K^{-T} R R^{-1} K^{-1} v_k = 0$$

$$v_i^T K^{-T} K^{-1} v_j = v_j^T K^{-T} K^{-1} v_k = v_i^T K^{-T} K^{-1} v_k = 0$$

Solving for camera viewpoint

Given 3 orthogonal VPs (at least two finite), can compute projection operator

$$R = \begin{bmatrix} R_{1c} & R_{2c} & R_{3c} \end{bmatrix}$$

$$\lambda v_i = KRe_i \qquad e_i = [1, 0, 0]^T$$

$$R_{ic} = \lambda K^{-1} v_i$$

Projecting to image space

Given K, R, and a position in 3D, we can find its corresponding 2D image location:

$$\lambda p_2 = KRP_3$$

What about the reverse?

Given K, R, and a 2D position on the image, what do we know about its 3D location?

What about the reverse?

Given K, R, and a 2D position on the image, what do we know about its 3D location?

$$(KR)^{-1}p_2 = \lambda P_3$$

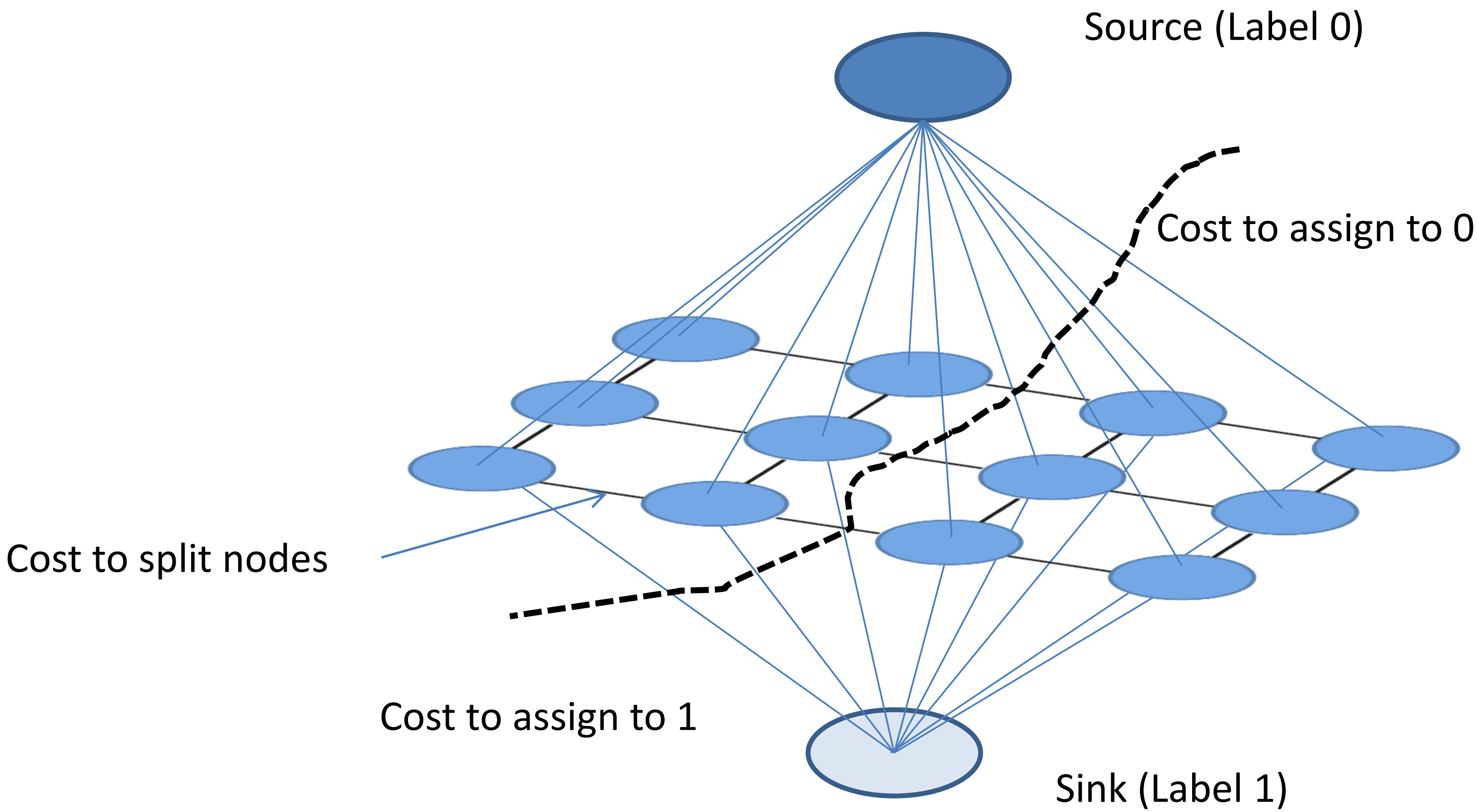
- Implies a line along which the 3D point lies
- Points on known surfaces can be localized

Modeling occlusions

User-defined boundary

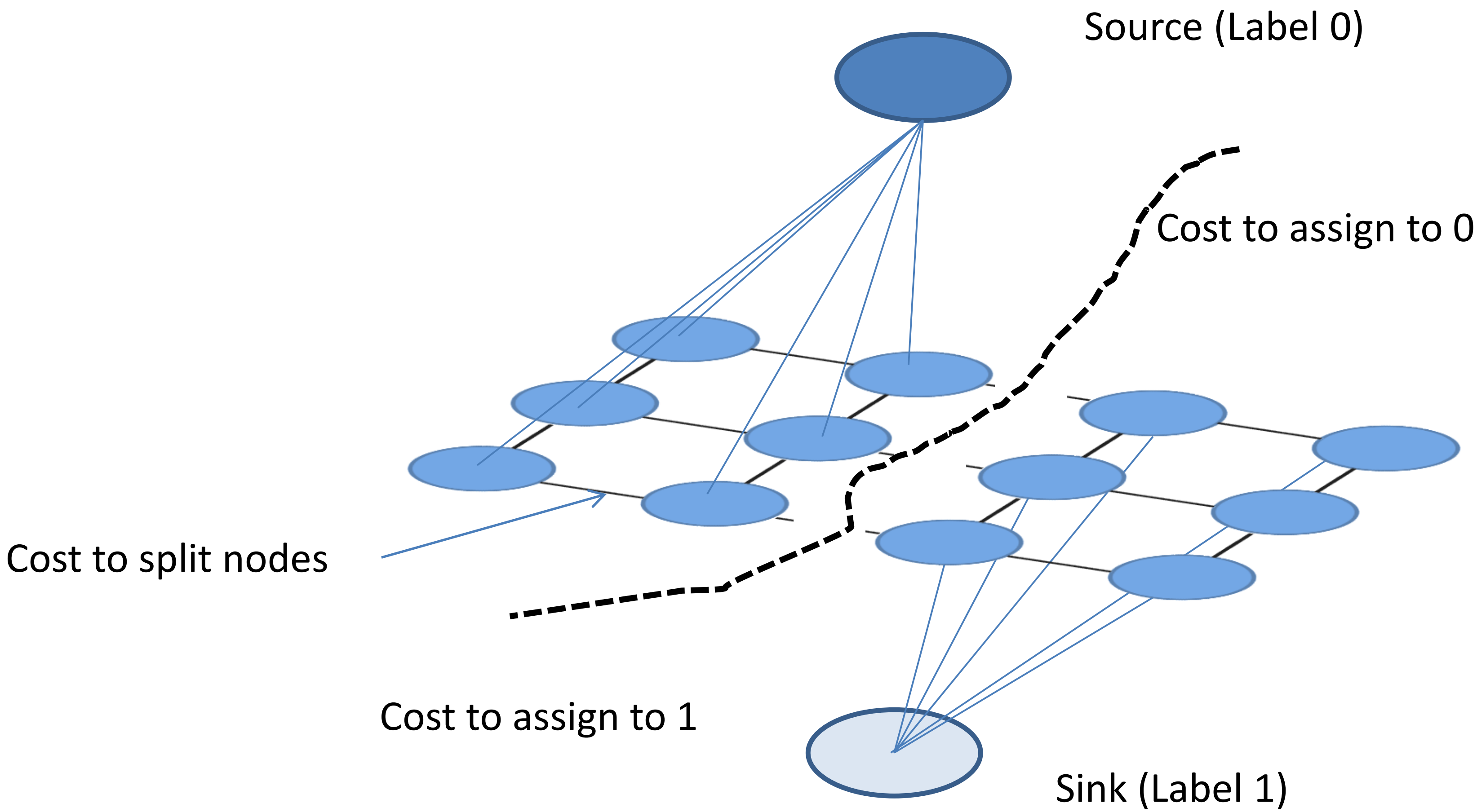
- Tedious/inaccurate
- How can we make this better?

Segmentation with graph cuts



$$Energy(\mathbf{y};\theta,data)=\sum_{i}\psi_1(y_i;\theta,data)\ \sum_{i,j\in edges}\psi_2(y_i,y_j;\theta,data)$$

Segmentation with graph cuts



$$Energy(\mathbf{y};\theta,data) = \sum_{i}\psi_1(y_i;\theta,data)\ \sum_{i,j\in edges}\psi_2(y_i,y_j;\theta,data)$$

Refined segmentation

Spectral matting

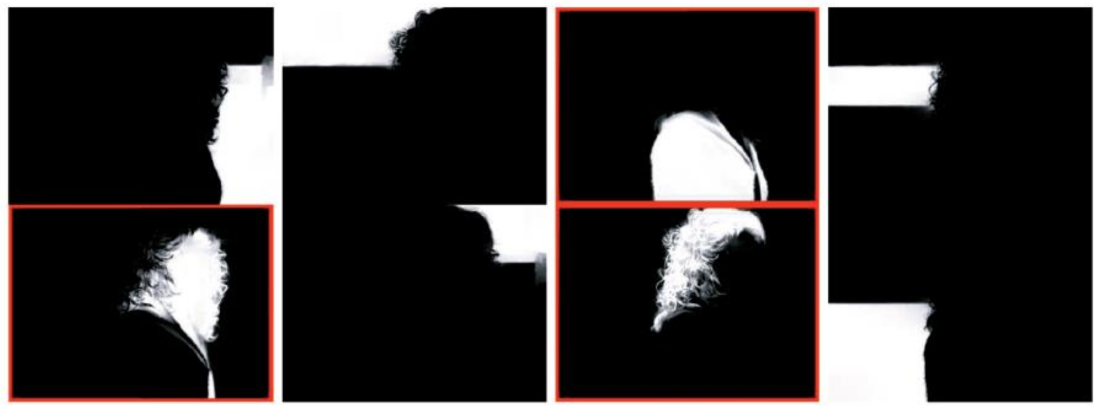
Spectral Matting

- Create NxN matrix describing neighboring pixel similarity (Laplacian matrix, L)
- Extract “smallest” eigenvectors of L
- Soft segmentation defined by linear combination of eigenvectors
  - Scribbles provide constraints to assign to foreground

[“Spectral Matting” Levin Rav-Acha Lischinski 2008]

Spectral Matting

image



spectral components

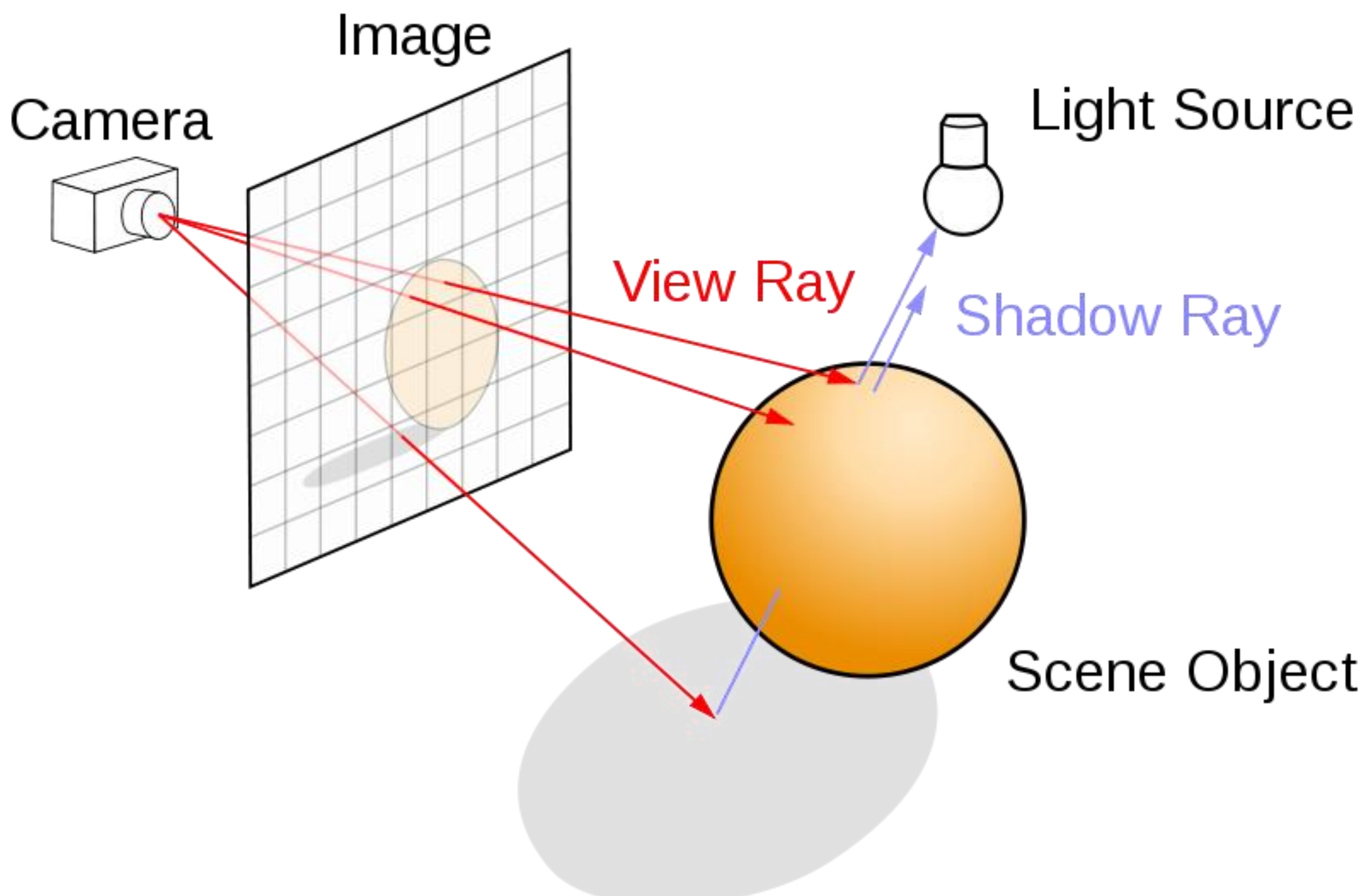
Spectral matting

Spectral matting

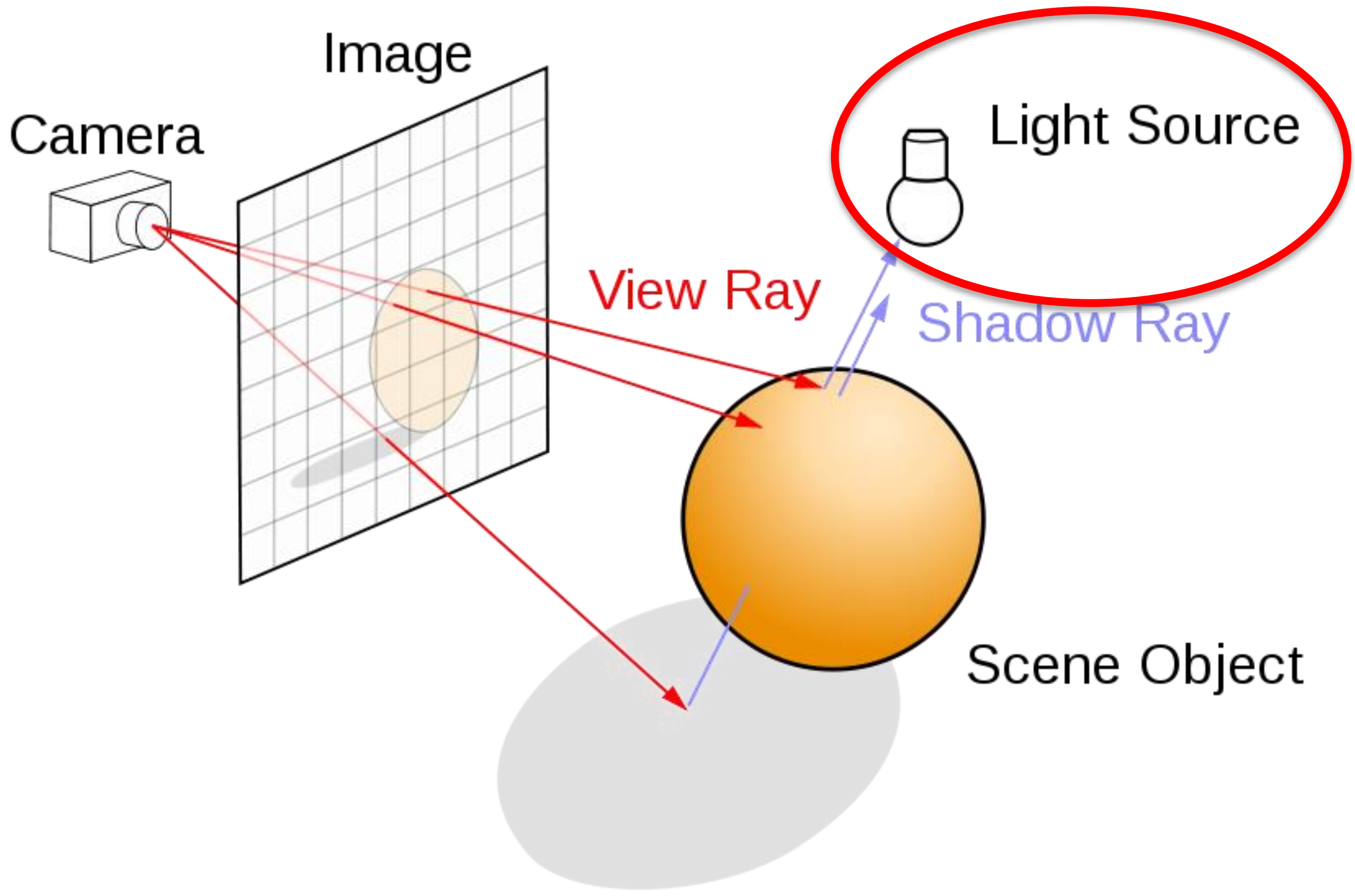
Segmentations as “billboards”

Segmentations as “billboards”

Rendering via ray tracing



Rendering via ray tracing



Insertion without relighting

…with relighting

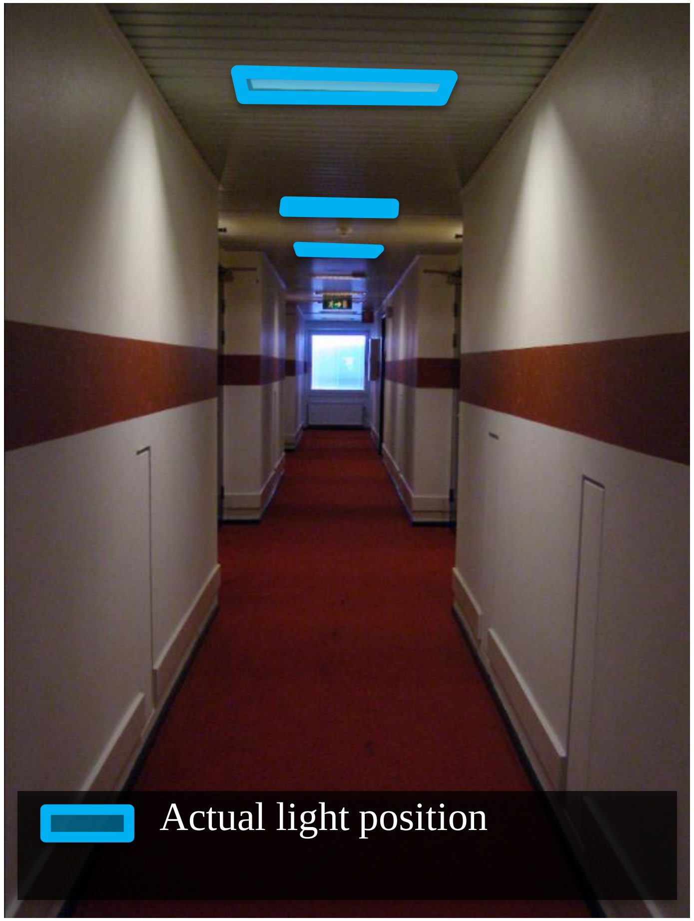
Estimating light

- Hypothesize physical light sources in the scene
  - Physical → CG representations of light sources found in the real world (area lights, etc)

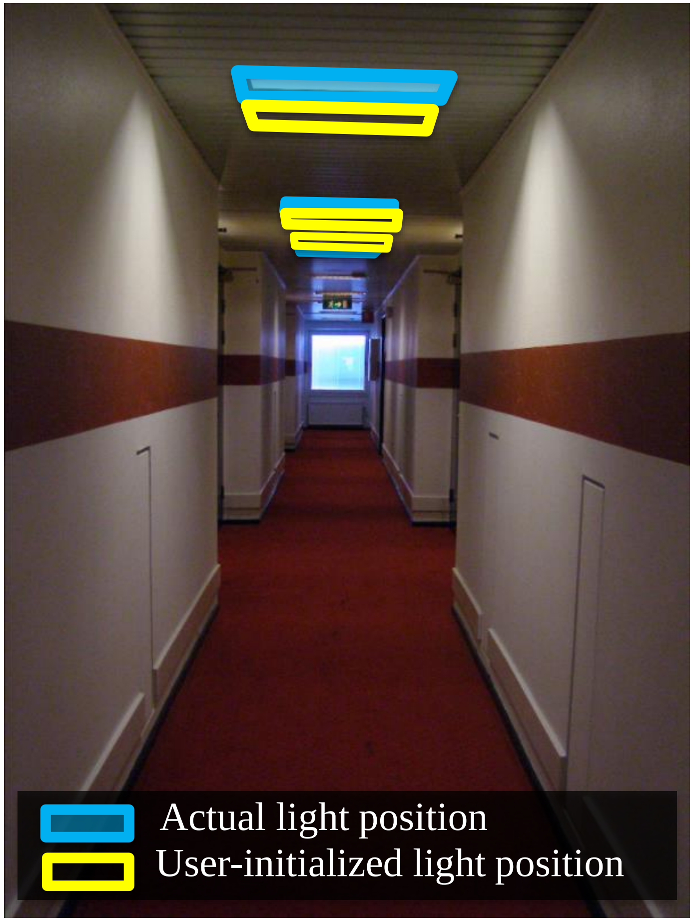
- Visible sources in image marked by user
  - Refined to best match geometry and materials
- User annotates light shafts; direction vector
  - Shafts automatically matted and refined

Lighting estimation

Lighting estimation

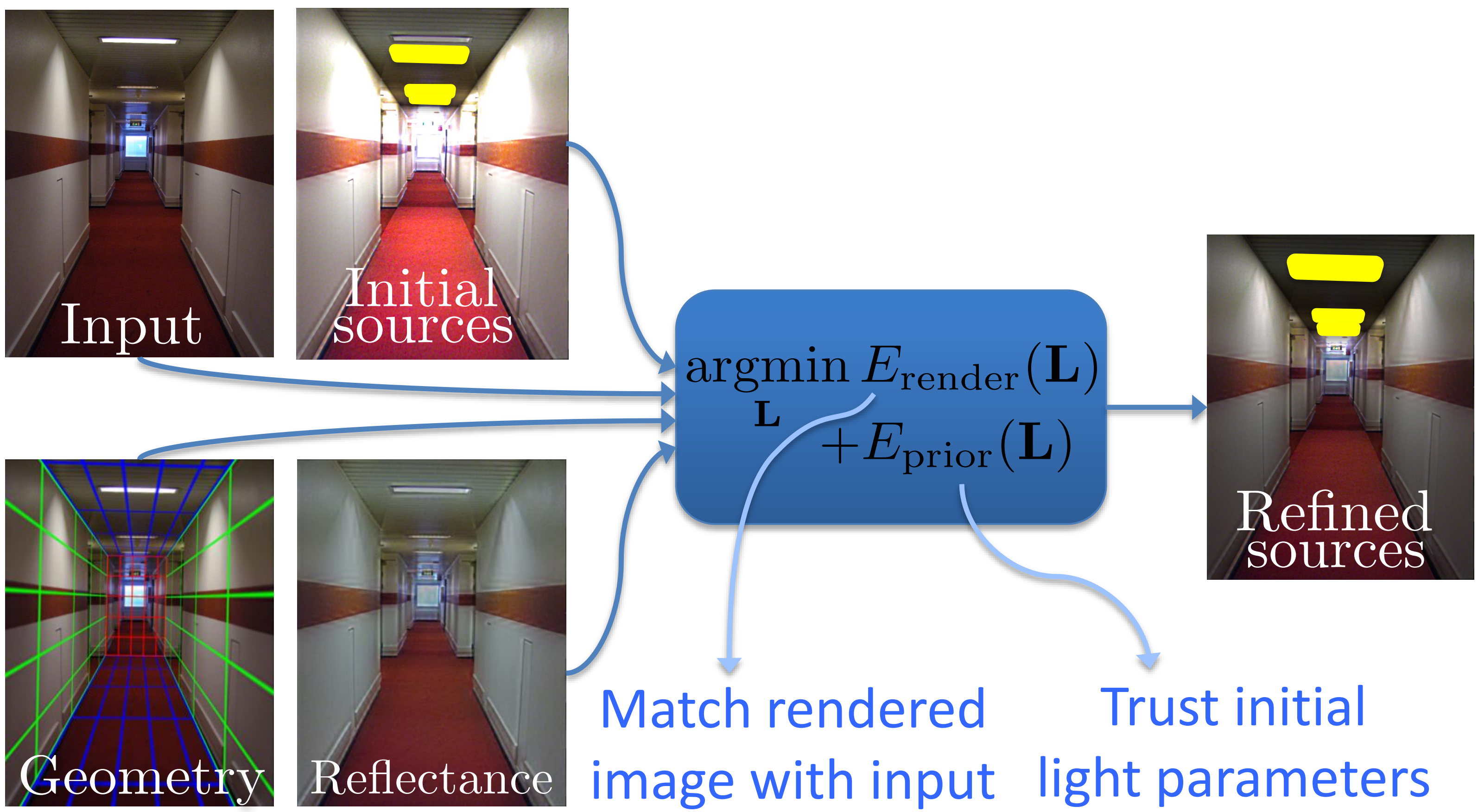


Lighting estimation

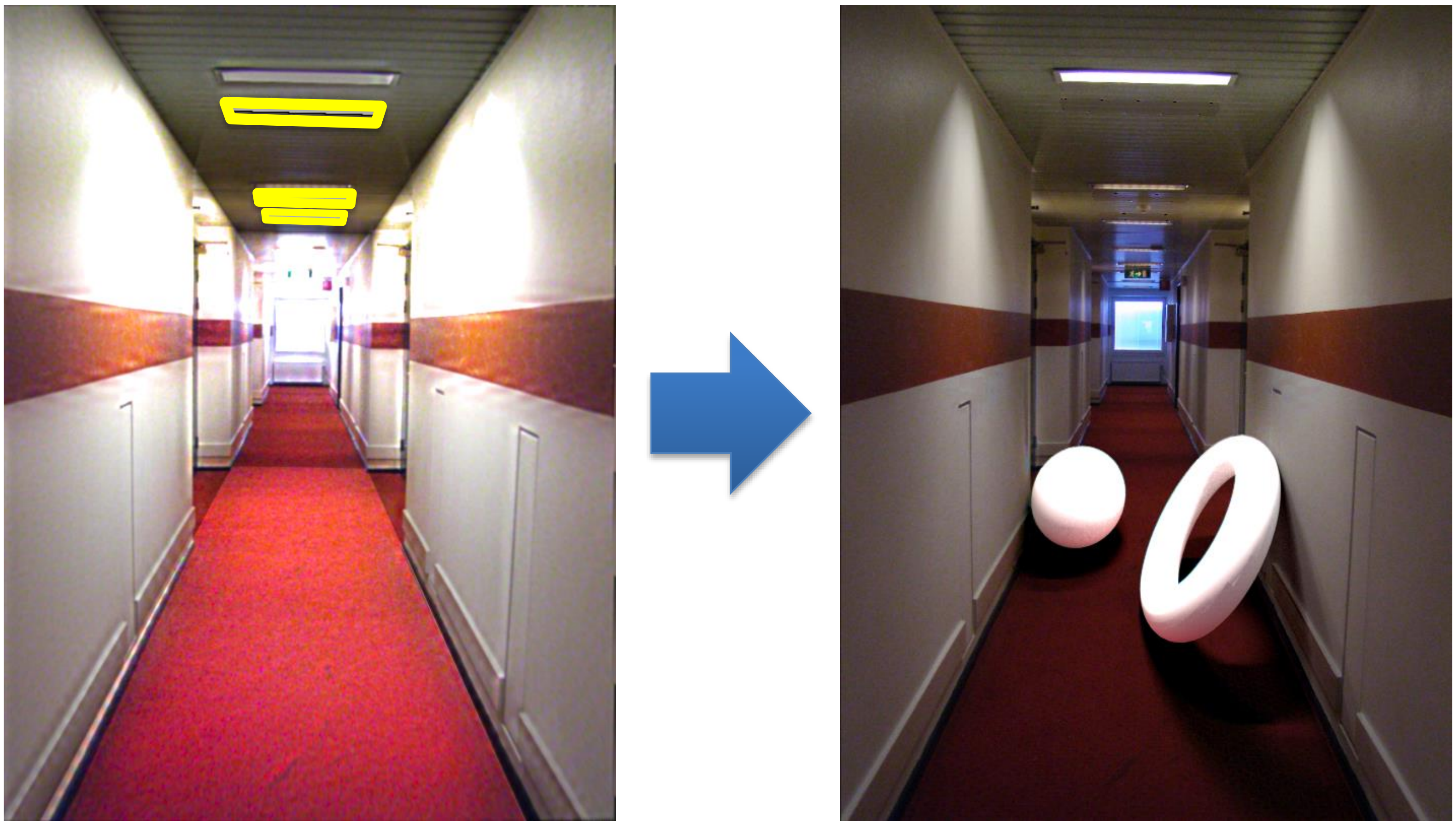


Light refinement

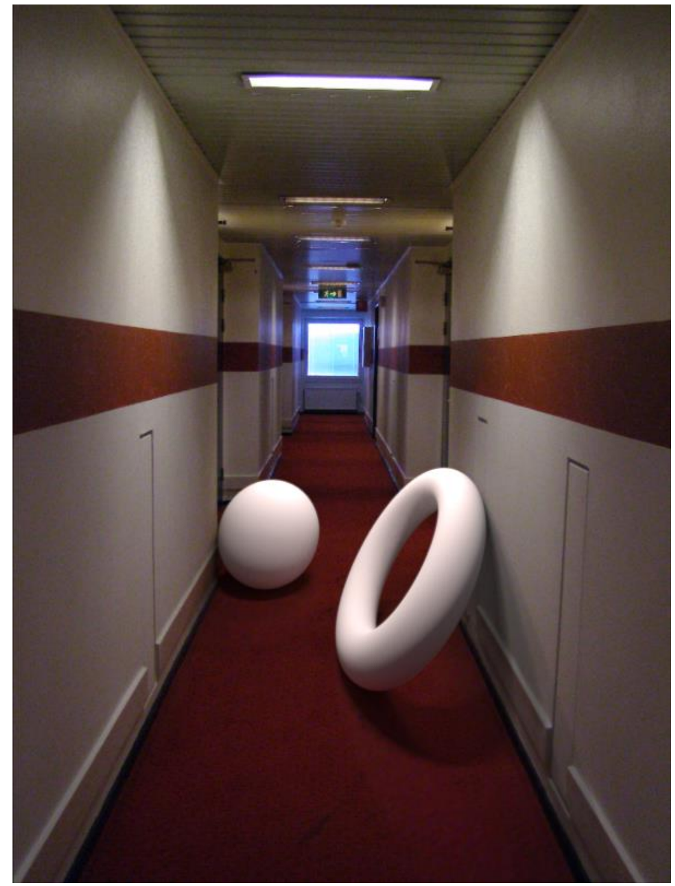
Match original image to rendered image



Initial light parameters

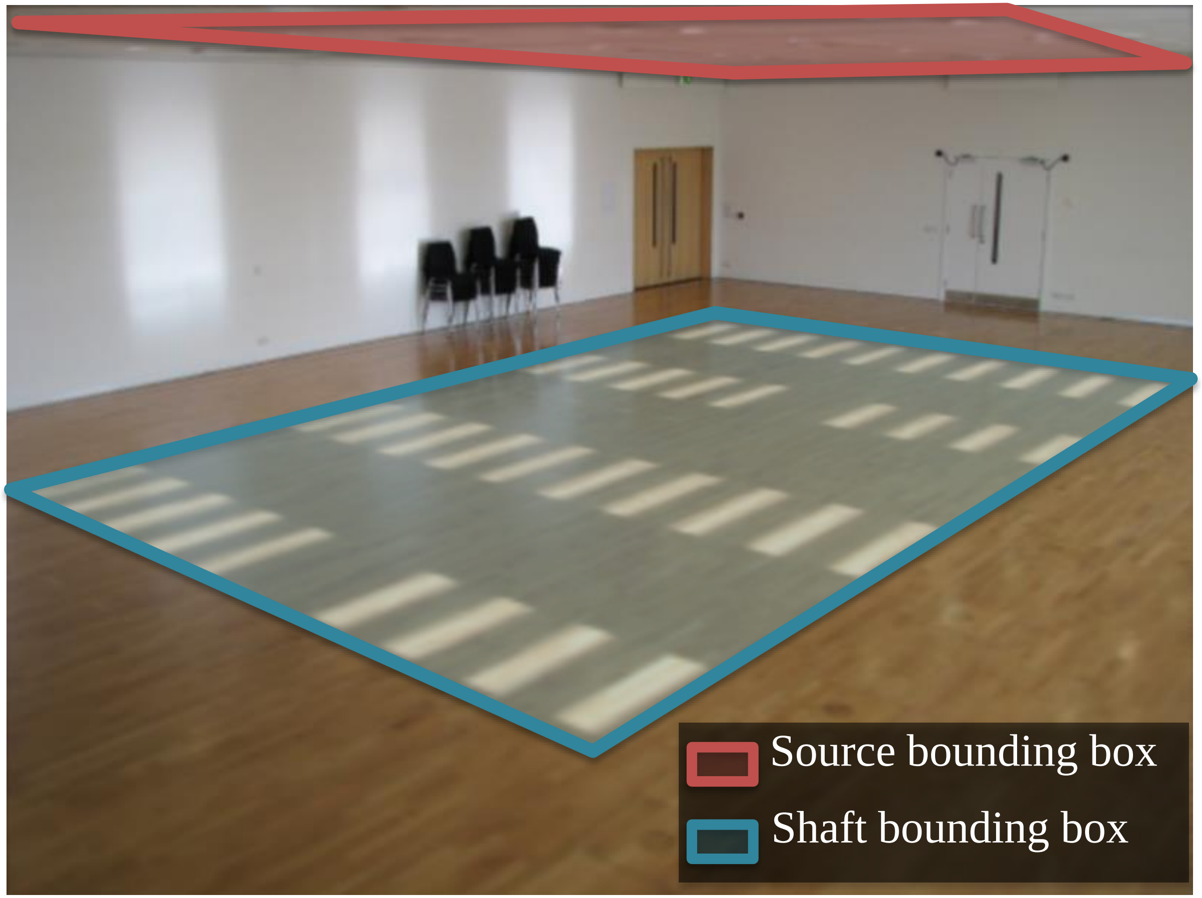


Refined light parameters



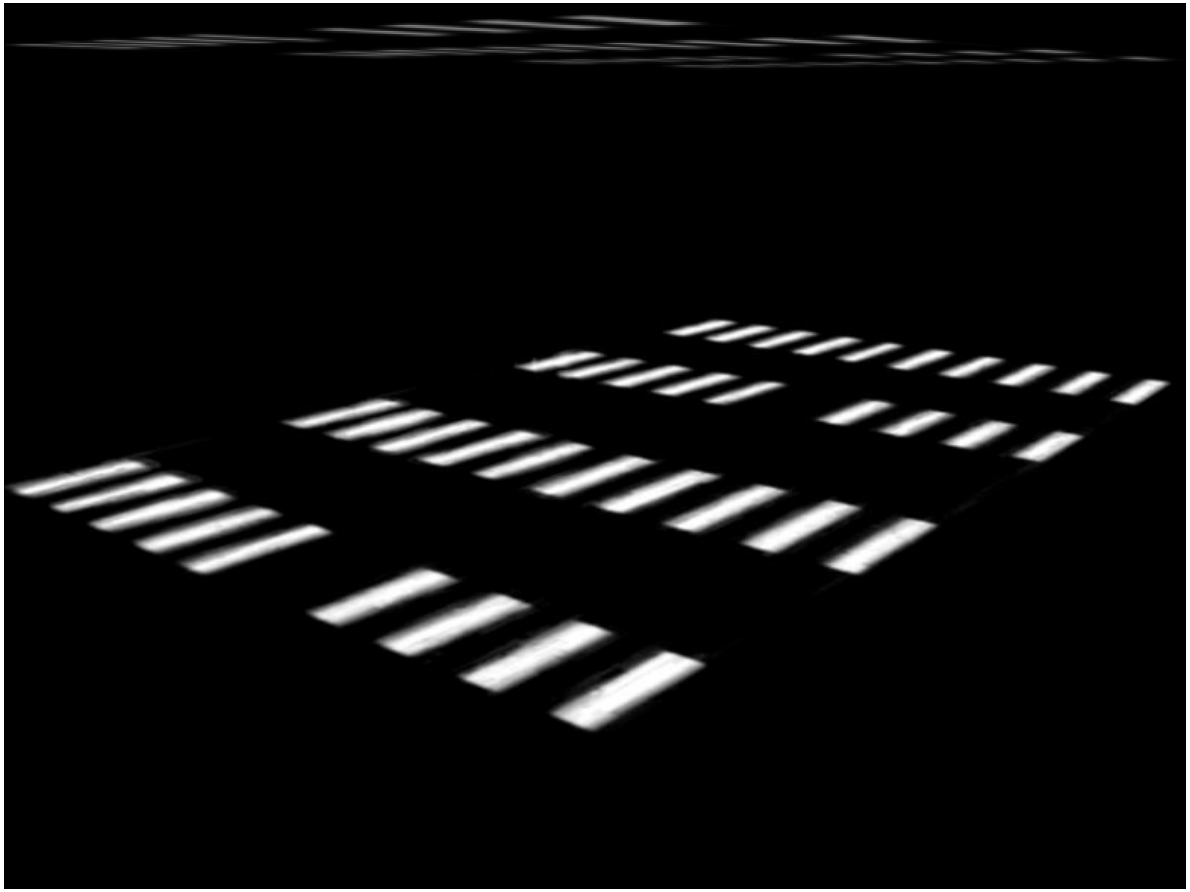
External light shafts

External light shafts



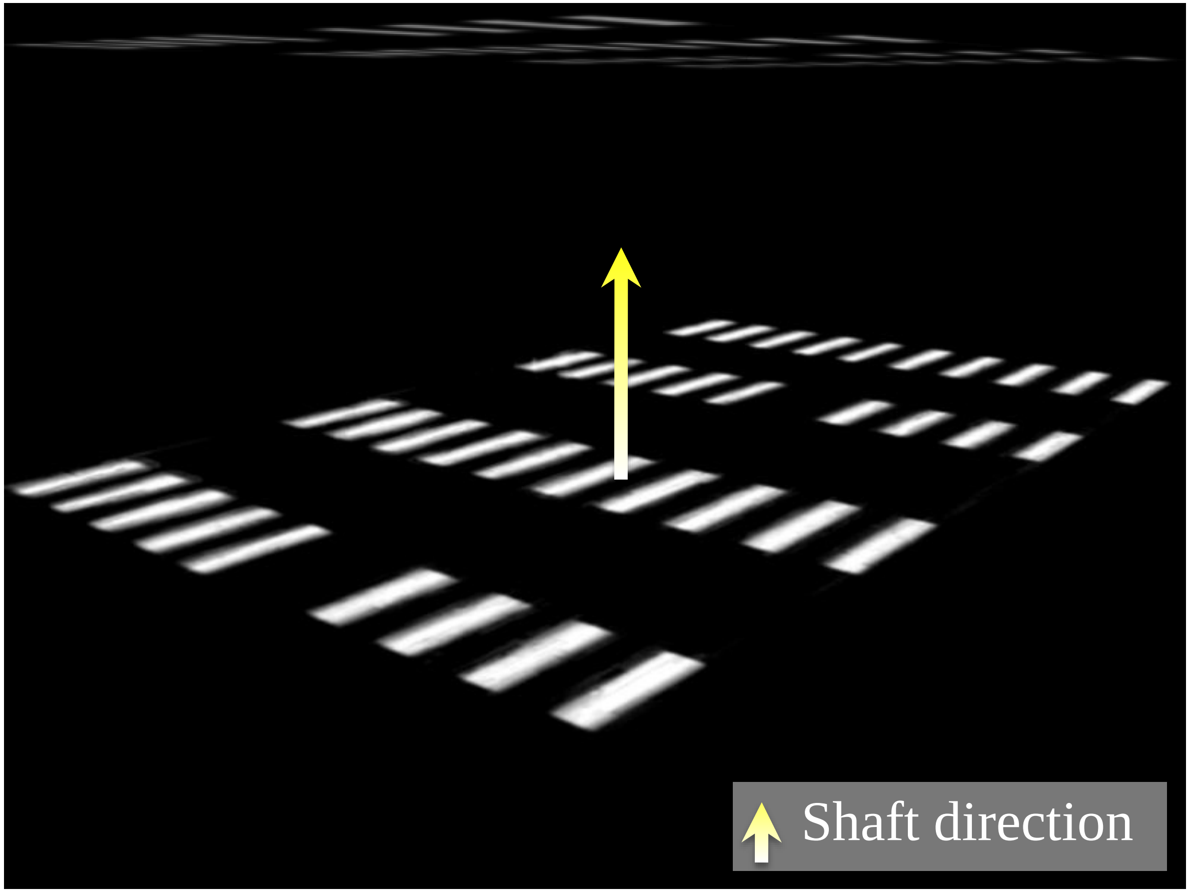
External light shafts

Shadow matting via Guo et al. [2011]

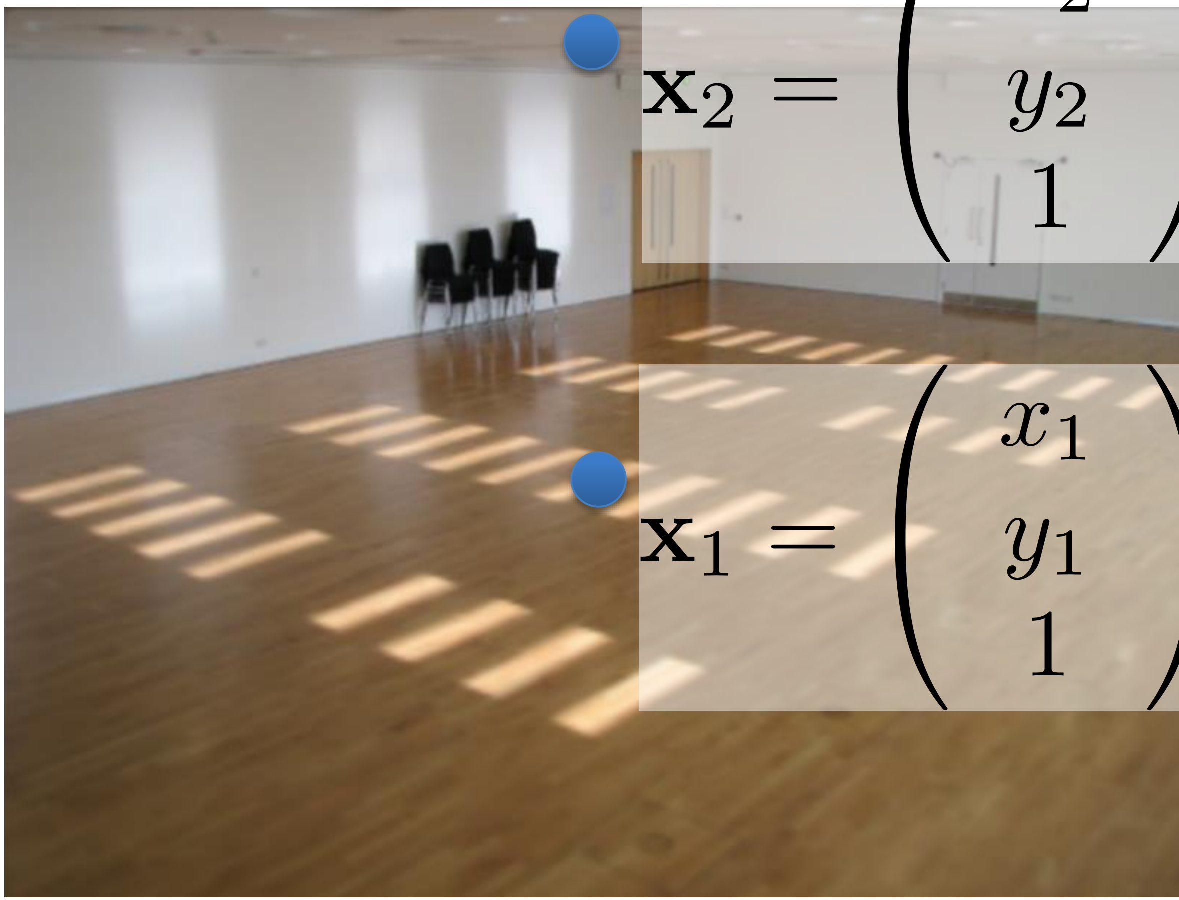


External light shafts

How to set direction of the shaft in 3D?



Setting light shaft direction



$$\mathbf{x}_2 = \begin{pmatrix} x_2 \\ y_2 \\ 1 \end{pmatrix}$$

$$\mathbf{x}_1 = \begin{pmatrix} x_1 \\ y_1 \\ 1 \end{pmatrix}$$

Light shaft result

Inserting objects

- Representation of geometry, materials and lights is now compatible with 3D modeling software
- Two methods of insertion/interaction
  - Novice: image space editing
  - Professional: 3D modeling tools (e.g. Maya)
- Scene rendered with physically based renderer (e.g. LuxRender, Blender's Cycles)

Final composite

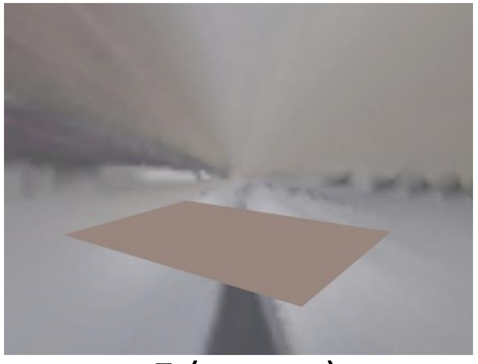
Additive differential technique [Debevec 1998]

composite = M.*R + (1-M).*I + (1-M).*(R-E).*c

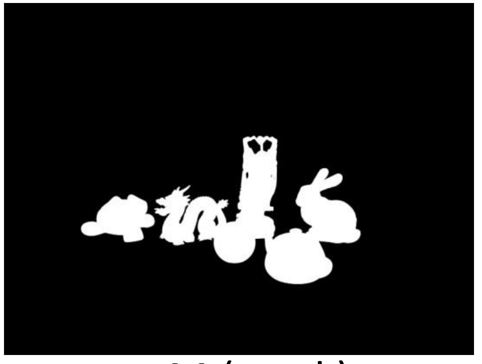
I (background)

c (composite)

R (rendered)



E (empty)



M (mask)

Blender demo

Putting it all together

Video

Research directions

- Can we do better with
  - Multiple images?
  - Videos?
  - Depth?
- Better scene understanding?
- How to insert image fragments?

Most recent version

Karsch et al. 2014:
http://vimeo.com/101866891

Summary

- We can accurately predict how a 3D object would look in a depicted scene by recovering
  - Viewpoint: camera matrix, single view geometry
  - Scene geometry: single-view geometry
  - Material: "intrinsic image approaches"
  - Lighting: solve for lights such that rendering reproduces image

- Next classes: interest points, alignment, and stitching